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Dedicated to FRANK JAMES WRIGHT, PH.D.

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FRANK JAMES WRIGHT, PH.D.
Professor *Emeritus* of Geology, Denison University

IN DEDICATION

This issue of the Journal of the Scientific Laboratories of Denison University is dedicated to Dr. Frank James Wright, whose good services at Denison, as Professor of Geology, extended over a period of twenty-five years (1924 to 1949).

During those years Dr. Wright served faithfully and well, not only as a skillful teacher but as a research worker and as a writer in the field of physiography and as an enthusiast who consistently inspired and assisted his majoring students to maintain a continuing interest in geology and to do graduate work in that field. Among these former students of Dr. Wright's, who have achieved graduate degrees in geology and who are now actively engaged in the profession of geology, are the five authors of papers presented in this special number of our Journal. They are but a few of many who have expressed an appreciation of the teaching and inspiration received from Dr. Wright during their undergraduate days at Denison and since graduation.

Dr. Wright, too, has been a contributing author of papers published in this Journal. His articles have dealt essentially with his extensive studies in land formations in the Appalachian Mountain ranges of the South. As typical references we may cite the following.

1. Vol. 23, Art. 8, 1928 (24 pp.); The Erosional History of the Blue Ridge.
2. Vol. 24, Art. 12, 1929 (6 pp.); Stream Piracy near Ashville, N. C.
3. Vol. 26, Art. 2, 1931 (108 pp.); The Older Appalachians of the South.
4. Vol. 29, Art. 1, 1934 (105 pp.); The Newer Appalachians of the South (Part I).
5. Vol. 31, Art. 3, 1936 (50 pp.); The Newer Appalachians of the South (Part II).

It is a privilege, for his former students and colleagues at Denison University and for the Denison Scientific Association and the staff of the *Journal of the Scientific Laboratories*, to dedicate the current issue of the Journal to Dr. Frank James Wright, as an expression of our appreciation and esteem.

W. A. EVERHART,
Editor.

THE PARAGENESIS OF PITCHBLENDE-BEARING VEINS[1]

DONALD L. EVERHART AND ROBERT J. WRIGHT[2]

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PLATE 1. Index map showing selected pitchblende-bearing deposits.

ABSTRACT

The age relations of pitchblende in twelve vein deposits are described. On the whole, pitchblende occupies a variable paragenetic position; in some deposits it is one of the earliest minerals to form and in others it is one of the latest. It is noted that in the pre-Cambrian deposits studied pitchblende is early in the mineral sequence, in late Paleozoic-early Mesozoic deposits it is variable in position, in late Mesozoic-early Tertiary deposits it is commonly late in the sequence.

The variable paragenetic position of pitchblende is ascribed to its probable deposition from a colloidal solution. Because of its high valences, uranium is particularly susceptible to coagulation from a colloid.

INTRODUCTION

This account of the paragenesis of a selected group of pitchblende-bearing vein deposits constitutes preliminary notes from a more comprehensive study of the geologic characteristics of primary uranium-bearing vein deposits throughout the world. This larger project has continued for some months as part of

[1] Submitted July 1951.

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the authors' duties as staff geologists in the Division of Raw Materials, U. S. Atomic Energy Commission.

In the preparation of the present paper, we have relied on published material, on information gained during personal contact with a number of geologists who have studied particular pitchblende deposits, and on personal observations. The discussion emphasizes deposits outside the United States, partly because of the relative scarcity of widely-available information concerning them, and partly because detailed studies of deposits in the United States are as yet only partially completed. The paragenesis of deposits in three selected domestic districts is described, however, for comparative purposes.

Only the paragenesis of veins carrying *pitchblende*—as opposed to uraninite—is considered herein. We have followed general usage in using the term pitchblende to describe the botryoidal, pitchy form of naturally occurring primary uranium oxides that contain less than $1\frac{1}{2}\%$ rare earths and thorium, and which generally occur in vein deposits in association with sulfides of the base metals.

For their assistance in the preparation of this paper, we wish to express our gratitude to Jean Brown and E. K. Judd, Division of Raw Materials, U. S. Atomic Energy Commission, New York City. Miss Brown made a special microscopic study of ores from the Carrizal Alto district, Chile, and Mr. Judd carried out some of the preliminary compilation on our behalf.

Following are brief descriptions of the paragenesis of pitchblende-bearing deposits in twelve selected districts (see Plate 1) together with a discussion of the salient general features and possible significance of the data.

PARAGENESIS OF SELECTED DEPOSITS

Carrizal Alto district, Chile

The Carrizal Alto district, in northern Chile, was one of the largest producers of copper during the beginning of the nineteenth century, but the area is now inactive. The ore deposits are in quartz veins trending N. 60° E. through diorite of the Andean batholith. Along the western edge of the district, diorite is in contact with Triassic quartzite. The veins contain actinolite, tourmaline, magnetite, and molybdenite, together with other sulfides, suggesting a fairly high temperature of deposition.

The general sequence of metallic minerals is as follows (7):

1. Magnetite, chalcopyrite
2. Hematite
3. Molybdenite, pyrite, cobaltite
4. Arsenopyrite
5. Niccolite
6. Chloanthite
7. Bornite and chalcopyrite
8. Calcite

Polished surface studies of selected ore specimens by Jean Brown indicate that pitchblende occurs in isolated masses and veinlets replacing and crosscutting magnetite and hematite, but is in turn intersected by arsenopyrite and late chalcopyrite. Thus the position of pitchblende in the mineral sequence appears

to be younger than hematite, but older than arsenopyrite, and conditions of medium temperature and pressure at the time of deposition are indicated.

Coeur d'Alene district, Idaho

Pitchblende has been found during the past two years in the lower levels of the Sunshine mine, which is an important silver producer of the Coeur d'Alene district, Idaho. Pitchblende-bearing veins are closely related to the Sunshine vein, which follows a tension fracture system trending east and dipping about 70° south. The mineral content of the pitchblende-bearing veins is similar to the Sunshine vein. Tetrahedrite and associated sulfides occur in a siderite-quartz gangue.

Age relations of the metallic minerals are as follows (16):

1. Pyrite
2. Arsenopyrite
3. Argentiferous tetrahedrite
4. *Pitchblende* and chalcopyrite

Cornwall district, England

Metalliferous ore shoots containing pitchblende have been known for many years at a number of localities in the extreme southwestern part of England. Virtually all of this pitchblende is associated with the copper ores that formed the basis for a large mining industry prior to 1900. Only two groups of mines, however,—the South Terras group near St. Stephen, Cornwall, and the Trenwith mine at St. Ives, Cornwall—have been consistent producers of uranium.

Base metals of a wide variety have been produced in quantity from Cornwall, and the distribution of the ore types is a classic example of temperature zoning.

The general mineral sequence has been recorded (6) as follows:

1. Cassiterite, quartz, tourmaline, and specular hematite.
2. Cassiterite, arsenopyrite, wolframite, chlorite, tourmaline, and quartz.
3. Chalcopyrite, wolframite, arsenopyrite, quartz, cassiterite, and chlorite.
4. Chalcopyrite, wolframite, arsenopyrite, quartz, fluorite, pyrite, and jasper.
5. Galena, sphalerite, pyrite, quartz, dolomite, chalcedony, sulfides and arsenides of cobalt and nickel, *pitchblende*, and fluorite.
6. Pyrite, marcasite, pyrolusite, hematite, limonite, and siderite.

Front Range district, Colorado

Since 1872, several vein deposits in the Colorado Front Range have intermittently yielded pitchblende ore as a by-product of precious metal production. Five of these deposits are in the Quartz Hill district, Gilpin County, Colorado, one is in the Lawson district of Clear Creek County, and one is explored by the Caribou mine, Boulder County.

The mineral sequence of the Quartz Hill and Lawson districts has been divided (3) into three stages of mineralization, as follows:

1. Quartz
2. Intergrown chalcopyrite (with associated minor sphalerite), pyrite, and *pitchblende*, deposited contemporaneously.
3. Quartz, siderite or dolomite, sphalerite, galena, pyrite, and chalcopyrite.

At the Caribou mine, two stages in the deposition of the vein minerals have been indicated (17), and the approximate sequence in each stage has been determined as follows:

Stage A.

1. Quartz
2. Pyrite
3. Sphalerite
4. Galena

Stage B.

1. Chalcedony and *pitchblende* (with minor pyrite)
2. Sphalerite and chalcopyrite (with minor pyrite)
3. Pyrite
4. Argentite with chalcopyrite
5. Proustite
6. Native silver

The paragenesis in the Caribou deposit thus is, in general, similar to that of the Quartz Hill district ores except for the more varied and complex mineralogy, particularly the presence of silver-bearing minerals. Well developed colloform texture, exhibited by the first four minerals in Stage B, is interpreted as indicative of deposition from a colloidal state.

Germany-Czechoslovakia districts

Deposits of the Bohemian Uplift region, in southern Germany and adjacent Czechoslovakia, have been worked for several centuries, and through long periods of history the mines have dominated the mineral economy of the world. Important quantities of silver, tin, tungsten, cobalt, bismuth, nickel, and copper have been produced. The area was revitalized during the middle of the last century by the discovery of uranium in the ores and the demand for uranium salts as ceramic pigments. Again, during the beginning of the present century, mining of uranium ores was reactivated by the Curie discovery of radium.

Pitchblende has been found in a number of deposits of the Bohemian Uplift. Most production has been derived from silver-cobalt-nickel veins in the Erzgebirge belonging to Bastin's nickel-cobalt-native silver ore type (2). The Joachimsthal deposits are considered herein as an example of this ore type. At Wölsendorf, pitchblende occurs in a second type of deposit—fluorite veins containing minor metallic minerals. A third type of deposit is represented in the Freiburg area, where pitchblende has been produced from silver-lead-dolomite veins.

Reports of the mineral sequence in the Joachimsthal veins are conflicting. It is generally agreed that vein quartz is early and most silver minerals are late;

conflict arises in the relations between pitchblende, cobalt-nickel minerals, and base metal sulfides. This is due partly to the fact that the cobalt and silver ores are segregated so that direct evidence of relative age is rare, and partly to the complex nature of the deposits, with common repetition and reversal of the mineral sequence.

Age relations are reported as follows:

Stage A. Milky quartz
Stage B. Hornstone (ferruginous chert)
Stage C. as reported in five publications:

Levy and Chaulette 1870 (12)	*d'Andrimont 1904 (5)*	*Step and Becke 1904 (15)*	*Zuckert 1926 (19)*	*Keil 1929 (9)*
1. Smaltite, niccolite	1. Cobalt-nickel-bismuth sulfides	1. Smaltite, chloanthite, niccolite	1. Native bismuth and silver	1. Smaltite, niccolite, silver
2. *Pitchblende*	2. *Pitchblende*	2. *Pitchblende*, pyrite, sphalerite, galena	2. *Pitchblende*	2. *Pitchblende*
			3 Cobalt-nickel arsenides	3. Cobalt-nickel arsenides
			4. Galena, sphalerite, arsenic	4. Galena, sphalerite, pyrite, chalcopyrite

Stage D. Argentite, proustite, cerargyrite, and native silver.

At Wölsendorf, pitchblende occurs in fluorite-filled fissure veins within granite. Aside from their importance as a source of metallurgic fluorite, the deposits are noted for a varied assemblage of secondary uranium minerals (14). Many of these minerals, including becquerelite, dewindite, fourmarierite, schoepite and others, had been known earlier only at Shinkolobwe.

The paragenesis of the vein minerals is as follows:

1. Carbonate gangue mineral
2. Chert and crystalline quartz
3. Fluorite of several generations; quartz and barite
4. Galena and chalcopyrite
5. Late carbonate
6. Fracturing of earlier minerals with deposition of quartz, fluorite, barite, hematite, and *pitchblende*

Great Bear Lake deposit, Northwest Territories, Canada

The silver and pitchblende ores from deposits at Echo Bay on the east shore of Great Bear Lake have been widely known since their discovery in May 1930. These deposits have constituted an important source of uranium since that date, and have been thoroughly studied mineralogically and geologically.

In the hydrothermal stage of mineralization in the Great Bear Lake deposits, four phases of mineral deposition have been reported (10) as follows:

Stage 1	*Pitchblende*
	Quartz
	Safflorite-rammelsbergite
	Cobalt-nickel minerals

Stage 2	Quartz
	Smaltite, cobaltite, and other cobalt-nickel minerals
Stage 3	Dolomite
	Lead, zinc, and copper sulfides
Stage 4	Ferruginous rhodochrosite
	Copper and silver sulfides
	Native silver

Lake Athabaska district, Canada

Pitchblende occurs in a large number of vein deposits of late pre-Cambrian or early Paleozoic age in the Goldfields district, north of Lake Athabaska, Canada. Most of the veins are comparatively simple and contain largely hematite, pitchblende, calcite and quartz, although sulfides, arsenides, selenides, hydrocarbons, and native metals are reported in a few deposits.

The following mineral sequence has been listed (13):

1. Calcite, hematite, and chlorite
2. *Pitchblende*, accompanied by hematite
3. Arsenides—rammelsbergite, niccolite, skutterudite, cobaltite, arsenopyrite
4. Sulfides—pyrite, chalcopyrite, galena
5. Selenides—berzelianite, umangite, clausthalite, klockmannite
6. Calcite, chlorite

Marysvale district, Utah

Pitchblende-bearing ore has been mined from vein deposits in the Marysvale district, Piute County, Utah since 1949. Mineralogic work on the Marysvale ores, particularly the primary ores being mined at progressively greater depths, is continuing. Preliminary studies (8) indicate the presence of the following primary minerals, and observations by Everhart suggest that the general sequence is:

1. Chalcedonic quartz
2. Coarsely crystalline quartz and fluorite
3. *Pitchblende*, pyrite, and jordisite
4. Calcite

Montreal River district, Ontario, Canada

Primary uranium oxide termed "coracite" was first reported in veins in the Montreal River district, on the east shore of Lake Superior in 1847. Pitchblende was rediscovered in the late fall of 1948 by Robert Campbell. Since that date several scores of pitchblende-bearing veins have been discovered in the area, and there has been brisk activity in the prospecting and development of newly discovered occurrences.

The mineral sequence observed in studies of ores from four deposits (18) is as follows:

1. Calcite, with hematite
2. *Pitchblende*
3. Hematite
4. Calcite

A more generalized sequence, observed by Everhart throughout the district, is as follows:

1. *Pitchblende* (intermixed with trace amounts of base-metal minerals)
2. Hematite (partly contemporaneous with pitchblende)
3. Carbonates and quartz

Shinkolobwe deposit, Belgian Congo

The Shinkolobwe deposit in the Belgian Congo, discovered in 1915, has become the foremost producer of uranium ore in the world. The geology and mineralogy of the deposits have been worked out in detail.

The mineral sequence (11) has been determined as follows:

1. Quartz, with associated monazite, tourmaline, and apatite.
2. *Pitchblende* and uraninite
3. Sulfides:
   a. Pyrite
   b. Linnaeite and cobalt-nickel sulfides
   c. Chalcopyrite
4. Dolomite and siderite

Urgeirica district, Portugal

The vein deposits explored by the Urgeirica mine in north central Portugal appear to be the most important of a sizable group of pitchblende-bearing veins occurring throughout the granite batholith of that area. These deposits were a source of the radium produced in France during the early part of the century and at present are sources of appreciable uranium ore.

The mineral sequence in the uraniferous quartz veins of the Urgeirica deposit is as follows (4):

1. White crystalline quartz
2. Hematitic jasper
3. Pyrite, sphalerite, galena
4. Microcrystalline quartz and *pitchblende*
5. Pyrite and chalcopyrite
6. Quartz, *pitchblende*, and pyrite

DISCUSSION AND CONCLUSIONS

From the above data it appears that pitchblende occupies a variable position in the sequence of vein minerals with which it is associated. In four areas, Great Bear Lake, Lake Athabaska, Montreal River, and Shinkolobwe, pitchblende is considered to be one of the earliest minerals formed, preceding a large variety of sulfides, sulfo-salts, and gangue minerals. In the other deposits, pitchblende occupies a more or less intermediate position in the mineral succession and formed in association with the common vein sulfides, particularly chalcopyrite and galena. In the Coeur d'Alene, Marysvale, and Wölsendorf districts pitchblende was among the last metallic minerals formed.

There is a suggestion of general correlation between geologic age of the deposits and the age relations of the pitchblende in them. In four of the areas

under consideration, the deposits were formed in late pre-Cambrian time. These are the Great Bear Lake, Lake Athabaska, and Montreal River deposits, all in the Canadian Shield, and the Shinkolobwe deposit, Belgian Congo. In each of these, pitchblende is an early mineral and precedes most of the metallic minerals contained in the veins. The deposits in the Cornwall, Joachimsthal, Urgeirica, and Wölsendorf districts are of late Paleozoic-early Mesozoic age. In these, the position of pitchblende ranges from medial, as at Urgeirica, to late, as at Wölsendorf. The deposits of late Mesozoic and early Tertiary age are primarily in the Cordillera of North and South America. These include veins of the Coeur d'Alene, Colorado Front Range, Marysvale, and Carrizal Alto districts. In the first three districts, pitchblende is late in the mineral sequence.

A possible explanation of the wide range in age relations between pitchblende and other vein minerals lies in the mechanism of its deposition. Pitchblende commonly forms botryoidal and spherulitic masses, this being one property by which it is distinguished from uraninite, which usually forms cubic crystals. Pitchblende of this habit is reported in most of the deposits described above. In several of the deposits botryoidal pitchblende is cut by irregular fractures in which later vein minerals have been deposited. This characteristic botryoidal habit is commonly taken to indicate that pitchblende has formed by coagulation of a colloid, and the mineral-filled fractures that traverse pitchblende represent shrinkage cracks formed during desiccation of the gel.

The coagulation of a colloid from solution is largely dependent on the presence of a suitable electrolyte. Introduction of an electrolyte bearing a charge opposite to the charge of the colloidal particles causes neutralization of the colloid, destruction of the dispersive property of the colloidal particles, and subsequent coagulation. Hence, deposition of a colloidal mineral is dependent primarily on the chemistry rather than the temperature of the solution from which it is forming, although under certain conditions decline in temperature alone can cause coagulation of a colloid. As a result, a mineral deposited by coagulation of a colloid can occupy a varied position in a mineral sequence in which the general order of crystallization is determined by the declining temperature of the parent ore solution.

The probable colloidal origin of pitchblende is believed to be the explanation of its variable position in the paragenetic sequence of vein deposits. Hutton (1) has noted that "with solutions of salts, trivalent ions have, in general, immensely greater coagulative power than divalent ions, and the latter in turn, much greater than univalent". Hence it would be expected that uranium, which has valences of 3, 4, and 6, should be readily coagulated from a colloidal solution. This property may be responsible for its common botryoidal habit.

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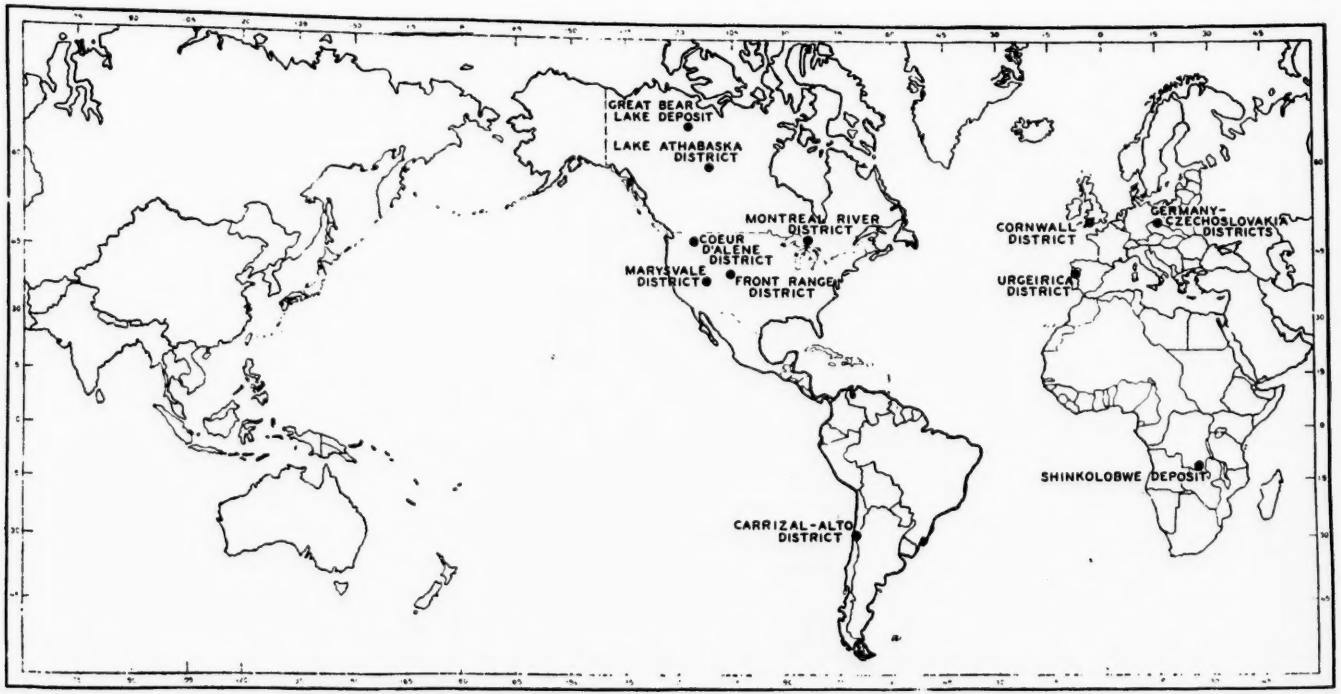

PLATE I. Index map showing selected pitchblende—bearing deposits

PARAGENESIS OF A URANIUM-BEARING VEIN AT CARIBOU, COLORADO[1]

HAROLD D. WRIGHT[2]

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INTRODUCTION

In 1945 a Geiger counter survey of the dump and underground workings of the Caribou Mine, located in Boulder County in the Front Range of Colorado, resulted in the discovery of uraninite on the 920 and 1040 levels (3). This mine had previously worked silver ores localized along shear zones cutting a quartz monzonite stock. The stock is elongated north-south and is approximately one and three-quarters miles long and about a mile wide. It was intruded into the Pre-Cambrian Idaho Springs formation and is believed to be Tertiary in age.

The uraninite-bearing vein, known as the "Radium Vein," trends east-west and dips 70 to 90 degrees north. The uranium-bearing portion has a width of about one to four inches, and is enclosed by an argillic and sericitic alteration halo up to three feet in thickness on either side. The Radium Vein is an off-shoot from a larger silver-bearing vein, the "No-name Vein," in which radioactive minerals have not been discovered.

A study of the mineralogy of the Caribou uraninite occurrence was undertaken as a part of a program for mineralogical studies of uraninite and uraninite deposits which is in progress at Columbia University under the sponsorship of the Atomic Energy Commission.

ACKNOWLEDGMENTS

This study has been carried on under the supervision of Professor Paul F. Kerr of Columbia University, director of the project. The writer gratefully acknowledges his advice and suggestions. Mr. Donald L. Everhart, of the Atomic Energy

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Commission, helped to formulate overall plans for the study and aided greatly in the collection of samples both in the field and from other collections previously made. Mr. Elmer Hetazer, Mine Superintendent at Caribou, donated a number of specimens of high-grade uraninite ore for study, and several large specimens were loaned by the AEC Raw Materials Operations office in New York.

COLLECTION OF SAMPLES AND METHODS OF ANALYSIS

Since a field study of the Caribou occurrence and other prospects nearby is being undertaken by the U. S. Geological Survey, field work for this study was confined to a brief examination of the deposit and collection of samples for laboratory study and analysis. Samples of vein material were collected at intervals along the Radium Vein and in the raise on the 1040 level.

Polished surfaces of the ore were studied with the reflecting microscope. The study yielded data on the texture of the uraninite, its relation to other vein minerals and the sequence of the vein filling. Thin sections of the ore aided in the study of relations of the ore minerals to the gangue and wall rock minerals.

GENERAL STATEMENT

The ore minerals recognized on polished surfaces are uraninite, pyrite, chalcopyrite, sphalerite, galena, argentite, proustite and native silver. Gangue minerals represented are quartz, calcite and barite. Two characteristic assemblages of ore minerals appear to represent different stages in the vein formation. In Stage A, which is thought to be the earlier, quartz, sphalerite and galena were deposited. Uraninite was deposited early in Stage B, a later stage. The other minerals of this stage are chalcedony, chalcopyrite, sphalerite, argentite, proustite, and native silver.

URANINITE

Two types of uraninite occur in the Caribou ore. One of these is a hard, dense, black material with pitchy luster, while the other is a soft, fine-grained, dull-lustered, porous, almost sooty material which fills fractures and coats open vugs in uraninite and sulphides and in some places appears to grade into the lustrous material. The hard variety shows varying degrees of luster and hardness. Both varieties contain inclusions of pyrite and lesser amounts of other sulphides. Under the microscope the lustrous uraninite almost always shows the colloform structure which characterizes the material described from other localities, as Great Bear Lake (1), Joachimsthal (5), and Katanga (4). This structure is illustrated by Figure 1. Radially arranged fractures, some filled with pyrite, are common in the botryoidal material. Although the hardness of uraninite is given as $5\frac{1}{2}$, even the "hard" variety of Caribou uraninite can be scratched with a steel needle.

COLLOFORM BANDING IN THE ORE

Colloform texture shown by four successively deposited minerals—chalcedony, uraninite, sphalerite, and pyrite—suggests a colloidal phase in the process of ore deposition, which was apparently maintained over a considerable portion

of the mineralization and through a considerable change in the composition of the solutions.

Chalcedony and uraninite are frequently banded rhythmically with thin pyrite bands. The structure is delicate and beautifully preserved, and is well brought out in the polished surfaces. Colloform texture has been cited by Lindgren (2) as a strong indication, if not proof, of deposition in the colloidal state. In their study of the mineragraphy of the ores of Great Bear Lake, Kidd and Haycock (1) accepted the colloform structure of the uraninite as proof of its depcsition in the colloidal state. Further evidence of colloidal deposition is seen in the radial fractures in uraninite botryoids, some filled with later pyrite. This

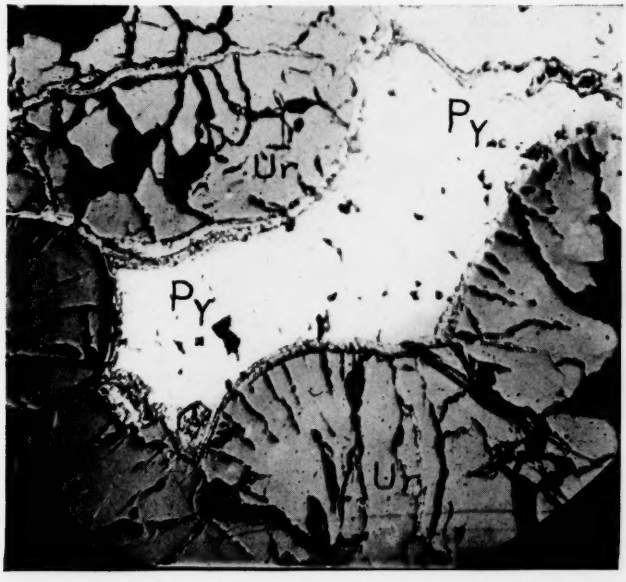

FIG. 1. Typical botryoidal structure shown by uraninite (Ur), with later pyrite (Py). × 123.

structure was attributed by Kidd and Haycock to the process of contraction and solidification of the colloid from which the minerals were deposited.

The large number of vugs filled with vein minerals and deposition by fracture filling rather than replacement suggest that the vein was formed at a fairly low temperature and close enough to the surface that pressure permitted the existence of open space. These suggestions as to temperature and pressure conditions of deposition are further supported by the evidence of colloidal deposition, which is favored by low temperature.

PARAGENESIS OF THE VEIN FILLING

In the study of paragenesis two main lines of evidence have been considered: (1) sequence of mineral deposition in veins and cavities, and (2) truncation of

earlier by later structures. In some cases replacement structures lent support to interpretations based upon other relations. Two lines of evidence suggest that Stage A, characterized by sphalerite and galena, preceded the uraninite-silver minerals stage:

(1) Fragments of sphalerite and galena as much as half an inch in width, apparently belonging to an earlier mineralization (Stage A), form inclusions within chalcedony and uraninite. Colloform uraninite also coats portions of the sphalerite-galena inclusions.

(2) Although galena was apparently not crystallized in Stage B mineralization it appears embedded in uraninite as isolated broken cleavages of irregular

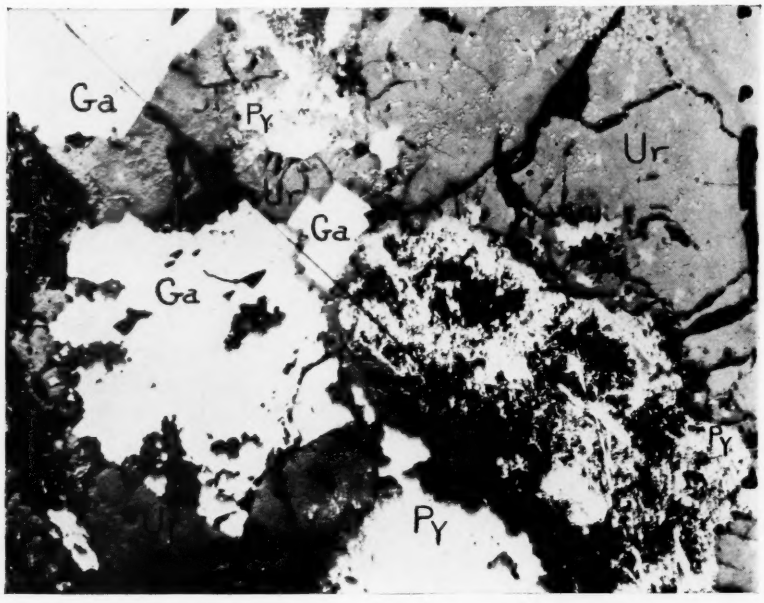

FIG. 2. Galena (Ga) engulfed and veined by uraninite (Ur). × 132

rectangular outline which are suggestive of fragments rather than crystal growth. Many of the galena grains have been fractured along the cleavage and the fractures filled with uraninite. Both cleavage outlines and fracture fillings indicate that the galena is earlier than uraninite, and thus earlier than Stage B. This relationship is illustrated in Fig. 2.

Stage A

The minerals of this stage are quartz, galena, and sphalerite. Quartz is the earliest and euhedral crystals line wall rock along vugs and veins. The formation of sphalerite as a vug filling overlapped the quartz deposition. Open space

remaining in partially filled vugs was filled with galena, which commonly cuts the sphalerite.

Stage B

Mineralization in Stage B began with deposition of chalcedony and colloform uraninite in veinlets and vugs. The uraninite in general forms a coating on chalcedony or on earlier fine-grained quartz and may replace these to a slight extent. However, some chalcedony is later than uraninite. Colloform structure of the uraninite does not parallel that of the chalcedony, as may be seen in Fig. 3. In places the uraninite is separated from the succeeding sphalerite by a

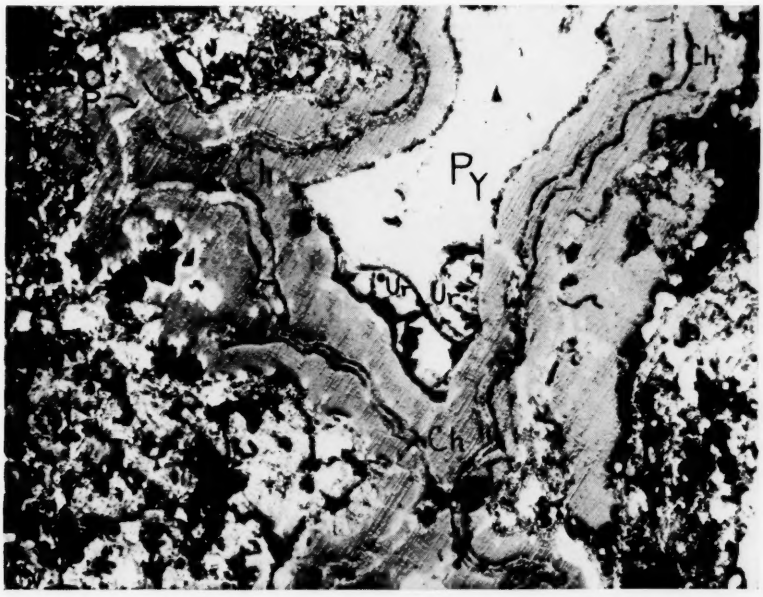

FIG. 3. Botryoidal uraninite (Ur) coating chalcedony (Ch) in vug filled by pyrite (Py). × 100.

very thin ribbon of pyrite or chalcopyrite. A little pyrite was deposited in the early part of Stage B. Some pyrite that forms brecciated fragments in chalcedony and remains in partial pseudomorphs of uraninite after pyrite is earlier than Stage B mineralization, but its relations to the sphalerite and galena of Stage A are not known. Fig. 4 shows pyrite partially replaced by uraninite.

In general the colloform uraninite is followed by a conformable band of sphalerite which replaces the uraninite preferentially along lines conforming to the botryoidal outline of the uraninite, or as randomly oriented replacement veinlets. Figures 5 and 6 illustrate deposition of sphalerite on uraninite, followed by pyrite; replacement of uraninite by sphalerite is seen in Fig. 6. The

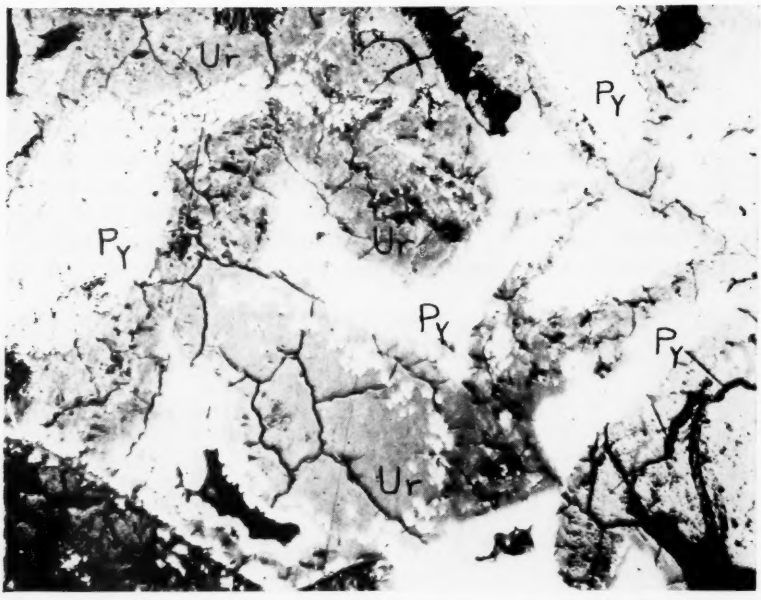

FIG. 4. Uraninite (Ur) veining and replacing pyrite (Py). × 98

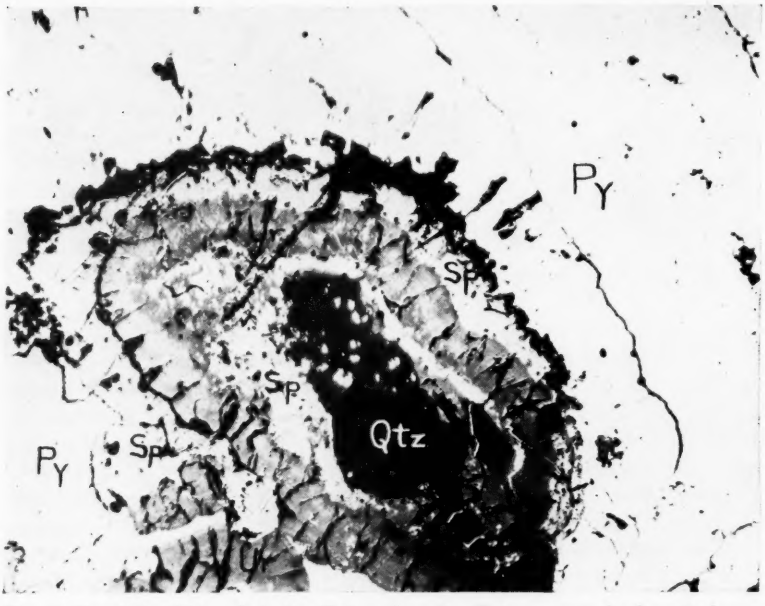

FIG. 5. Uraninite (Ur), sphalerite (Sp), and pyrite (Py) successively deposited around quartz (Qtz) grain. The uraninite is partly replaced by sphalerite. × 97.

inner boundary of the sphalerite layer maintains the botryoidal form of the uraninite and commonly shows crystal terminations penetrating the succeeding botryoidal pyrite band.

Chalcopyrite occupies a variable position in this sequence of deposition. It rarely forms bands similar to the other minerals described, but, in part, appears in tiny blebs in the sphalerite band, most commonly along the inner margin. This feature is attributed by Ridland (3) to exsolution. In places it also forms small veinlets in uraninite and quartz. Some chalcopyrite appears late in the vug sequence, associated with argentite and proustite. Here, again, its form is that of small rounded blebs in other minerals.

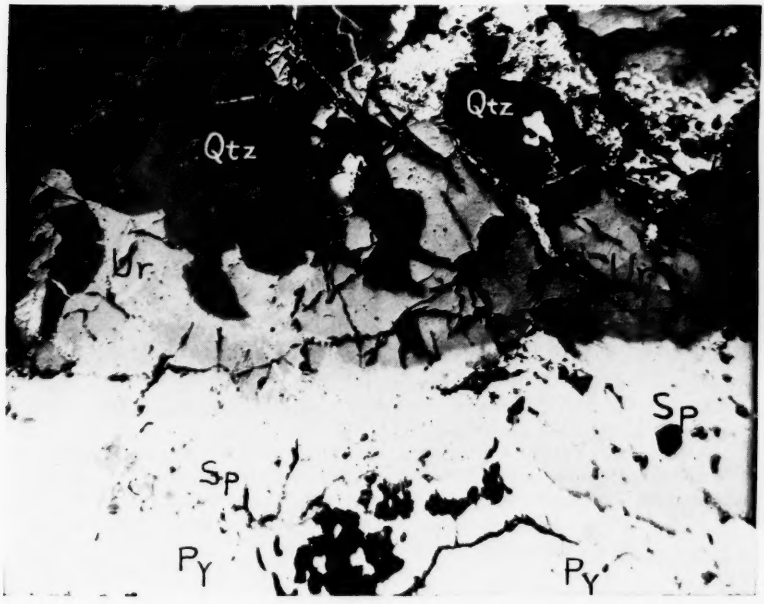

FIG. 6. Uraninite (Ur), sphalerite (Sp), and pyrite (Py) successively deposited on quartz (Qtz). Botryoidal uraninite shows partial replacement by sphalerite. × 187.

Pyrite follows sphalerite in the sequence and maintains the form inherited from the colloform uraninite. Fine, dark lines of impurity within the pyriet conform to the outlines of the colloform banding and in places delineate crystal outlines facing the interior of the vug. The identification of the colloform iron sulfide as pyrite rather than marcasite is based upon its isotropism, as well as the brassy yellow color where visible in hand specimen. Besides the colloform variety, pyrite occurs in numerous microscopic veinlets cutting uraninite, sphalerite and quartz.

Pyrite completes the filling in many vugs, but in some it is followed by silver minerals, which do not maintain the colloform structure. Argentite follows pyrite in the sequence, and a part of the argentite is closely associated with chalcopy-

rite. The argentite cuts across and replaces all of the earlier minerals of the filling, pyrite, chalcopyrite, sphalerite, uraninite and quartz. Proustite is closely associated with argentite and in a few cases is seen to replace it. Native silver is probably a result of near-surface oxidation, and is found as vug fillings in the form of "wire" silver.

Summary of Paragenesis

The above evidence indicates the following sequence in the deposition of the minerals of the Radium Vein:

Stage A

1. Quartz
2. Pyrite?
3. Sphalerite
4. Galena

Stage B

1. Chalcedony and uraninite (with minor pyrite)
2. Sphalerite and chalcopyrite (with minor pyrite)
3. Pyrite
4. Argentite with chalcopyrite
5. Proustite
6. Native silver

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MORPHOLOGY OF LAYER LATTICE SILICATES[1]

THOMAS F. BATES[2]

ABSTRACT

The platy and fibrous characteristics of layer lattice silicate minerals are well known. Recent electron microscope work on clays has revealed the existence of another crystal habit, the cylindrical tube. This form was first found to be characteristic of the minerals endellite and halloysite, and more recently has been recognized in electron micrographs of natural and synthetic chrysotile. It is to be expected in layer lattice minerals provided (1) opposite sides of the same layer differ in dimensions and (2) the bonds between the layers are sufficiently weak. In silicates the first condition commonly exists in minerals of the 1:1 structural type where one silicon-oxygen sheet is combined with a sheet of either the gibbsite or brucite type. The second condition is related to the degree of randomness in the stacking of successive layers, the presence of interlayer water, and other factors. With increase of interlayer bond strength a transition may be expected from tubes to fibers with curved surfaces and finally to plates which increase in size as the tendency to curve decreases. The changes in size and shape from endellite to nacrite in the kaolinite group and the morphological relations exhibited by synthetic chrysotile, natural chrysotile, and antigorite can be explained in this manner.

INTRODUCTION

The planar arrangement of three out of the four oxygen ions belonging to each SiO_4 tetrahedron of the sheet structure silicates results in the platy crystals which are characteristic of the minerals in this group. Other factors such as the size and arrangement of ions within the unit cell and conditions of growth determine whether the plates will be equidimensional or elongated in one direction. In the latter case laths or even fibers may result but it is generally assumed that the planar arrangement of the atoms is preserved even though their extent in one direction in the plane of the sheet is very limited. Some of the minerals have platy and fibrous varieties which crystallize under different conditions and do not occur together. Commonly, however, the variation in form may be found within a single small specimen. Thus, the electron micrograph (Figure 1) of kaolinite $[(OH)_8Al_4Si_4O_{10}]$ from Zettlitz, Hungary shows not only the typical equant, pseudohexagonal plates, but also more elongated, lath-like crystals.

In 1948 electron microscope work revealed that the layer lattice mineral halloysite $[(OH)_8Al_4Si_4O_{10}]$ occurs in the form of cylindrical tubes (Bates,

[1] Presented at the meetings of the American Crystallographic Association held at the Pennsylvania State College, April 1950. Submitted for publication August, 1950.

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Hildebrand, Swineford 1949). Figure 2 shows some of the characteristics of these forms such as the cross section of the tube at A, so-called multiple tubes at C, and bifurcated tube ends. The tubes are commonly split longitudinally (B) as a result of dehydration of the mineral endellite [$(OH)_8Al_4Si_4O_{10}\cdot 4H_2O$] from which it is believed halloysite is formed. Further work (Bates, Hildebrand,

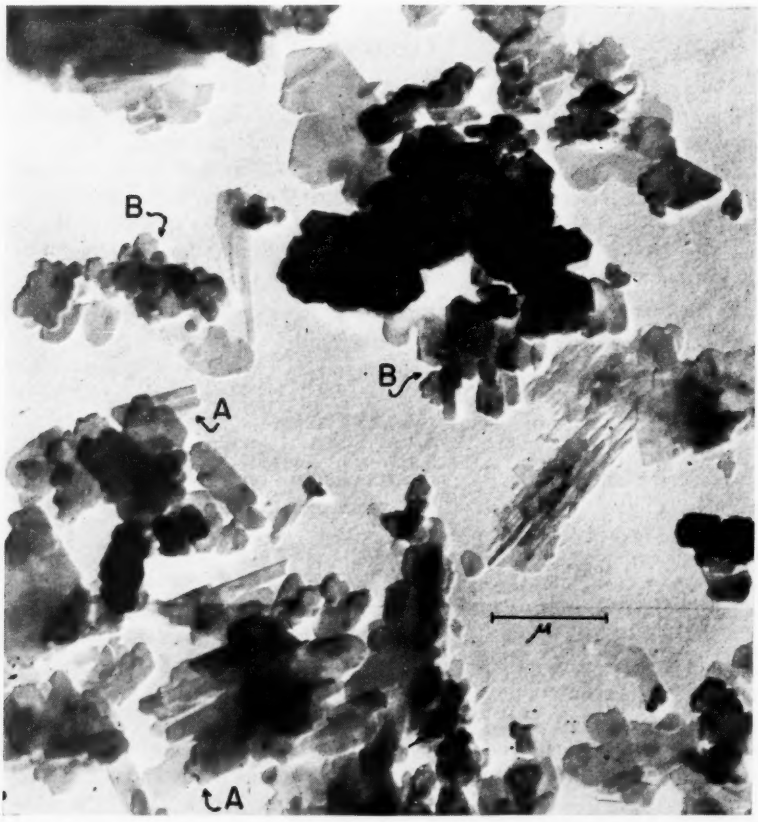

FIG. 1. Kaolinite from Zettlitz, Hungary. (A) Elongated crystals, (B) Aggregates of oriented plates.

Swineford 1950) indicates that the surface of the cylinder corresponds to that of the sheet which in kaolinite is planar. This interpretation has been useful in explaining many of the x-ray diffraction and optical characteristics of this mineral.

The structural picture offered to explain these cylindrical crystals is illustrated in Figure 3. According to Hendricks (1938) the structure of endellite (Figure 3B) is the same as that of kaolinite (Figure 3A) with the exception that

a sheet of "oriented water molecules" between adjacent layers causes them to be farther apart. These minerals have the 1:1 structure where, in each layer of unit cell dimensions along the a and b axes, a sheet of SiO_4 tetrahedra is combined with a sheet of $Al(OH)_3$ octahedra by the replacement of four hydroxyl by four oxygen ions. It was Pauling (1930) who first pointed out that these

FIG. 2. Halloysite from Real County, Texas. (A) Oblique view of end section, (B) Split and partially unrolled tube, (C) Multiple tubes.

sheets do not exactly fit and curvature would result. In a theoretical single layer of kaolinite the six oxygen ions on one side would occupy a distance along the b axis of 8.93 Å while the six hydroxyl ions on the other side of the same layer would occupy the spacing of 8.62 Å as in gibbsite [$Al(OH)_3$], and curvature would result. However, because of the existence of adjacent layers less than 3 Å distant, interlayer bonds in the mineral are sufficiently strong to "stretch" the hydroxyl ions to fit the larger spacing of opposite oxygen ions and plates

are formed. In endellite, however, the presence of the water layer places opposing oxygen and hydroxyl ions farther apart and so weakens the interlayer bonds that curvature results (Figure 3C). Calculations based on the lattice parameters of kaolinite for the dimensions of the tetrahedral layer, of gibbsite for those of

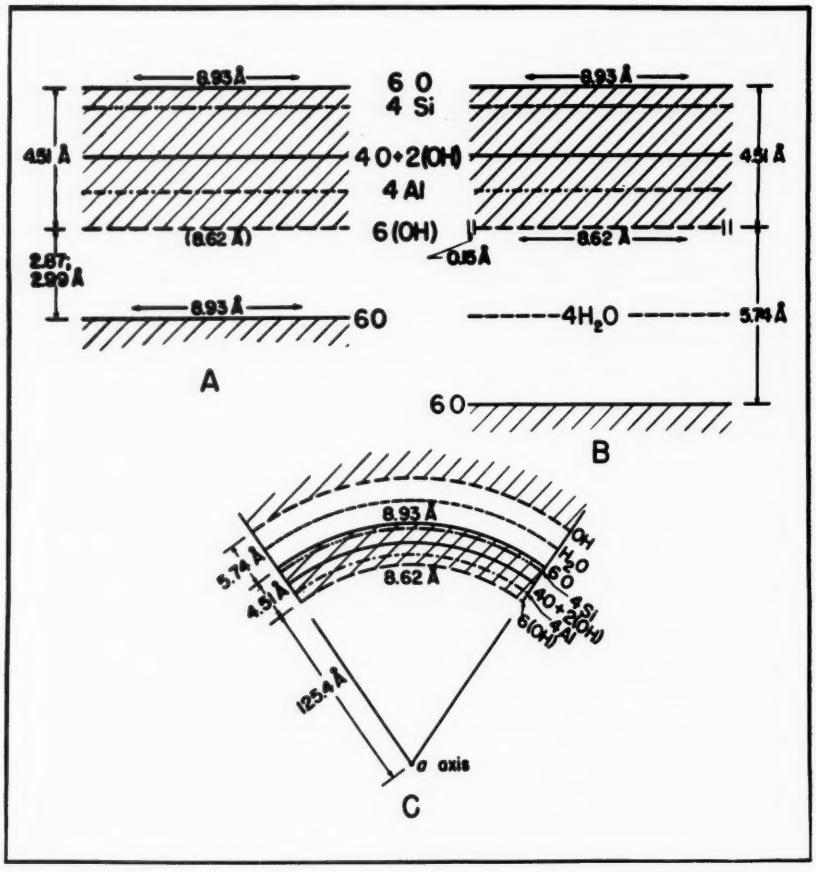

FIG. 3. Diagrammatic representation of the structure of kaolinite and endellite. (A) Arrangement of layers in kaolinite, (B) Arrangement of layers in endellite according to Hendricks, (C) Proposed arrangement of endellite layers.

the octahedral layer, and the appropriate thickness of the 1:1 unit lead to values for the minimum inner diameter of the tubes of from 250 to 600 Å. Measurements in the electron micrographs yield values which check with the calculated data. Upon the change of endellite to halloysite with removal of interlayer water, opposing oxygen and hydroxyl ions approach, strain is set up, and the tubes split longitudinally.

FACTORS CONTROLLING CURVATURE

The tubular crystals of endellite and halloysite represent what might be considered an extreme case of the curvature first discussed by Pauling. However, the existence of such forms suggests that a more critical evaluation is necessary of the factors which control morphological variation in layer lattice minerals, silicates or otherwise. In analyzing the variation in terms of curvature of the layers, two factors are significant. The degree of curvature depends upon (1) the variation in lattice dimensions on opposite sides of the same layer and (2) the strength of the interlayer bonds.

The first condition is to be expected in sheet structure silicate minerals of the so-called 1:1 type. Here, as just pointed out in the case of kaolinite, sheets of silicon ions in tetrahedral coordination with oxygen alternate with sheets of other cations (commonly aluminum or magnesium) in octahedral coordination with oxygen and hydroxyl ions. The result is an arrangement where one side of the unit cell contains oxygen ions and the opposite side hydroxyl groups. The space in the plane of the sheet occupied by the anions is controlled by the size, charge, and number per unit distance of the associated cations. Minerals having the 1:1 structure, and therefore subject to curvature because of variation in lattice dimensions within the layer, are the members of the kaolinite group, the serpentines, amesite, and cronstedite.

More of the layer lattice silicate minerals belong to the 2:1 structural type where in each layer, a sheet having octahedral coordination of anions around cations lies between two sheets of silicon oxygen tetrahedra. In this case if the dimensions of octahedral and tetrahedral sheets differ, growth in one direction in the plane of the sheet will be limited and fibers may result. Curvature, however, is not likely. Minerals of the 2:1 structural type include the micas, montmorillonite, talc, pyrophyllite, and many others.

The second condition affecting the degree of curvature is more difficult to analyze. The strength of the bond between anions of opposing layers will be controlled primarily by charges at the layer surfaces. These arise from ion substitution within the sheets, structural defects, and polarization of the anions. Sheets of different composition, such as H_2O, between adjacent layers may weaken the link between them and act as flexible units which will allow the crystals to assume more easily the configuration involving the least strain. Direct measurements of interlayer bond strength are difficult but such criteria as interlayer distance and the degree of randomness in the stacking of successive layers may be used as an indication of the forces present.

CORRELATION OF MORPHOLOGY WITH LATTICE DIMENSIONS AND RANDOMNESS

Table 1 lists the layer lattice silicates having a 1:1 structure, shows the degree of misfit of the sheets which combine to make the layer, and gives data on interlayer distances and randomness.

The kaolin group provides a particularly good example of the correlation of morphological change with increasing randomness and interlayer distance. Here, in all the minerals, there is a marked difference in the ideal size of the tetrahedral

and octahedral sheets forming the 1:1 layer. Yet in nacrite with no randomness and, therefore, greater relative interlayer bond strength the pseudohexagonal crystals are planar and relatively large. Similar plates in dickite and kaolinite become progressively smaller as randomness increases, and as Gruner (1932, p. 84) intimated, it is probably the tendency of the sheets to curve that limits the lateral extent of the crystals. In the case of endellite the presence of interlayer water coupled with almost complete randomness and large interlayer

TABLE 1

Morphological and Structural Data of 1:1 Silicate Minerals

MINERAL	MORPHOLOGY	LATTICE COMPOSITION AND DIMENSIONS*				INTERLAYER DISTANCE*	INTERLAYER RANDOMNESS
		Tetrahedral Layer			Octahedral Layer		
		Cations	a_0	b_0			
Nacrite	Hexagonal plates 1 to 5 mm. in diam.	4 Si	8.94	5.14	*Gibbsite Type:* 4 Al in six octahedral positions $a_0 = 5.06$, $b_0 = 8.62$	2.95	None
Dickite	Hexagonal plates 1 μ to 1 mm. in diam.		5.14	8.94		2.91	Slight
Kaolinite	Hexagonal plates .25 μ to 3 mm. in diam.		5.14	8.93		2.95	Considerable
Halloysite	Tubes, commonly split, .05 to 15 μ long		5.14	8.93		3.15-0.15	Great
Endellite	Tubes .05 to 15 μ long, .02 to .2 μ in diam.		5.14	8.93		5.74	Great
Antigorite	Large irregular plates	4 Si	5.43	9.25	*Brucite Type:* 6 Mg in six octahedral positions $a_0 = 5.38$, $b_0 = 9.32$		Slight Considerable
Natural Chrysotile	Extremely long, thin fibers		5.33	9.2			
Synthetic Chrysotile	Tubes 0.1 to 10 μ long, .02 to .25 μ in diam.		5.33	9.2			
Amesite	Tabular hexagonal crystals up to 1 cm. in diam.	2Si, 2Al	5.30	9.2	3 Mg, 2 Al, 1 Fe'' in six octahedral positions		Slight
Cronstedite	Trigonal prisms commonly about 1 mm. in diam.	2Fe''', 2Si	5.48	9.49	6 Fe'' and Fe''' in six octahedral positions		Considerable

* All dimensions are in Angstrom units.

distance so weakens the interlayer bonds that curvature is complete and the crystals grow in the form of tubes. This structural picture indicates that halloysite is formed by dehydration of endellite. Splitting and unrolling of tubes of varying size and perfection results in the large variation in the morphology of specimens of this mineral and accounts for many of the properties which have heretofore been considered anomalous.

It has been shown recently that the serpentine minerals are structurally analogous to the kaolinites with six magnesium ions rather than four aluminum ions in the octahedral layer (Warren and Hering 1941 and Aruja 1945). The

analogy also applies morphologically, for antigorite occurs in plates of widely varying dimensions whereas chrysotile fibers are tubular and have many of the characteristics of endellite and halloysite. Figure 4 is an electron micrograph of Arizona chrysotile taken by Hillier which shows that each asbestos fiber is in reality a tube and that multiple tubes (A) also occur (Turkevich and Hillier

FIG. 4. Chrysotile from Arizona showing tubular characteristics. (A) Multiple tubes, (Courtesy of Dr. James Hiller).

1949, Hillier 1949). Synthetic chrysotile grown by Bowen and Tuttle (1949) crystallizes in larger, well-developed tubes which are commonly multiple and sometimes show an interesting conical development. The morphological characteristics and the analogy to the minerals of the kaolinite group have been discussed in a recent paper (Bates, Sand, and Mink 1950). Synthetic antigorite grown by Dr. K. C. Tu at the University of Minnesota consists of nearly perfect pseudohexagonal plates which bear a striking resemblance to those of kaolinite.

From the standpoint of the factors previously discussed, the plates and tubes of serpentine are to be expected. As shown in Table 1, a variation in lattice dimensions exists between the tetrahedral and the octahedral sheets of the 1:1 unit. In antigorite, according to Aruja's figures, the a_0 dimension of the tetrahedral sheet is larger than that of the theoretical octahedral sheet whereas the b_0 dimension is smaller. This relationship would tend to produce platy crystals. In chrysotile, on the other hand, both dimensions of the lattice are smaller than those of the ideal octahedral layer. In addition, greater randomness than in antigorite indicates weaker interlayer bonds. As a result curvature takes place and tubes are formed.

Amesite $[(Mg,Fe)_4Al_2(Al_2Si_2)O_{10}(OH)_8]$ (Gruner, 1944) and cronstedite $[(Fe,Al,Ca)_{4-6}(Fe_2Si_2)O_8(OH)_{10}]$ (Hendricks, 1939) both occur in crystals with relatively large dimensions in the plane of the sheet. The situation here is not so clear because of lack of data on the dimensions of ideal octahedral layers containing the cations shown in the table. For the present it is only possible to assume that the substitutions in both tetrahedral and octahedral layers have resulted in sheets of similar dimensions. This is particularly true in cronstedite where there is considerable randomness and the interlayer bonds are presumably sufficiently weak to permit curvature if a discrepancy in dimensions were to exist.

SUMMARY

In layer lattice minerals the dimensions of the sheets making up the layers and the strength of interlayer bonds play important roles in determining the size and shape of the crystals. In sheet structure silicates of the 2:1 structural type a discrepancy in the dimensions of the sheets causes strain which fosters development of laths and fibers rather than plates. In minerals of the 1:1 type, however, the strain is relieved most easily by curvature of the layer. The degree of curvature from plates at one extreme to tubes at the other, will vary with the strength of the interlayer bonds.

The minerals of the kaolinite and serpentine groups illustrate these principles. By using interlayer distance and the degree of randomness of successive layers as a measure of interlayer bond strength, a correlation is obtained between these factors and the morphology of the crystals. Amesite and cronstedite also belong to the 1:1 structural type of layer lattice silicates but more data on these minerals is needed before a reliable interpretation of the morphology can be made in terms of the structure.

ACKNOWLEDGMENT

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CHAZYAN REEF FACIES RELATIONSHIPS IN THE NORTHERN CHAMPLAIN VALLEY[1]

PHILIP OXLEY[2]

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ABSTRACT

Four stratigraphic sections of Chazyan Crown Point and lower Valcour deposits are described in detail. They lie along a line trending from the type section at Chazy, New York, eastward through Isle La Motte, Vermont, a distance of about six and one-half miles. The two central localities display well-developed reefs, preponderantly of *Stromatocerium* spp. The other sections are of non-reefy lithology.

Zonation, and correlation between sections, is explained and comparisons and contrasts are drawn between those of reef and normal facies. Reef deposits are shown to be markedly thinner than their normal equivalents, and are interpreted as small bank-reefs from which finer sediments have been winnowed.

Comparison of the faunules shows marked concentration of sponges, hydrocorallines, corals, bryozoans and cephalopods in the reef masses. The reported range of *Maclurites magnus* Le Seuer at Chazy, New York, is extended and its value in local correlations affirmed.

INTRODUCTION AND ACKNOWLEDGMENTS

Ordovician Chazyan reef deposits of the type area have been frequently observed in the course of a regional stratigraphic study. Reefs of middle and upper Chazyan age occur in sections located in Figure 1. Others are found as

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far south as Essex, New York. Although these examples of biohermal sedimentation promise little in an economic way as petroleum reservoirs, their development in the type Chazy is noteworthy. Excellent opportunities are afforded for surface observation and comparison of the physical and paleoecological aspects of both reef and nearby synchronous, basinal facies.

Percy Raymond (1924, p. 72–76) described from Isle La Motte, Vermont, "The oldest coral reef". This accumulation, primarily of the coral, *Lamottia Heroensis* Raymond, lies some 60 feet below the top of the Day Point formation

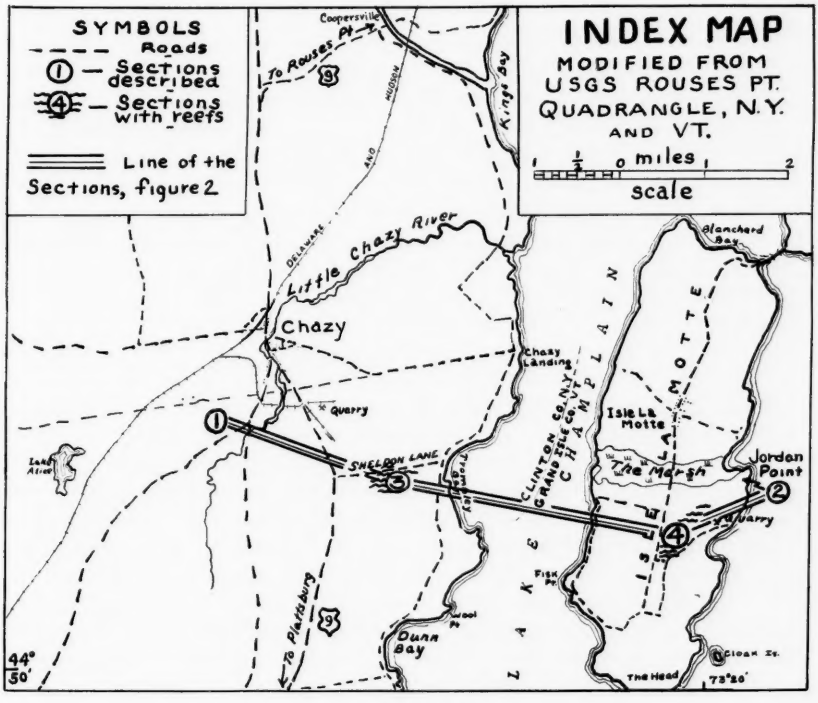

FIG. 1. Index Map

(Lower Chazy). Only on Isle La Motte have true reefs been observed at this horizon. There are, higher in the Chazy of the Champlain valley, much more strongly and widely developed bioherms, though not primarily of corals. Their fauna and distribution have received attention in only limited localities (Raymond, 1906; Hudson, 1931). It remains to describe them fully and to interpret their significance in terms of Chazyan paleogeography and history.

The present study is confined to descriptions of two sections of the later Chazyan reef facies and two closely adjoining sections of synchronous, what we shall call "normal" or basinal facies. These are shown in Figure 1. More complete

treatment of the stratigraphy of the type Chazy, and the reefs of other horizons within the group, is planned for later publication.

The writer expresses appreciation for the guidance of Professor Marshall Kay of Columbia University in the choice and conduct of the present research, and to the directors of the James F. Kemp Fund of that university for assistance in its completion. The work has been generously supported, also, by the New York State Museum and aided by its members. The contents of this paper are, however, solely the responsibility of the author.

GENERAL STRATIGRAPHY

The Chazy group of lower Middle Ordovician age is preponderantly a sequence of fossiliferous limestones of diverse character, overlying a transgressive basal sand. It was, in part, first described by Emmons (1841). The three divisions recognized at Chazy, New York, by Brainerd and Seely (1888, p. 323–330) were named by Cushing (1905, p. 368) Day Point (oldest), Crown Point, and Valcour. They reach maximum observed thickness of about 950 feet at Valcour Island, New York. The divisions, since elevated to formational rank, display overlap-offlap relationships from the Canadian border 70 miles southward to the vicinity of Crown Point, New York. West of the Champlain thrust the group is underlain by the Beekmantownian Bridport dolomite (Cady, 1945) and overlain by calcilutites, here designated "Lowville".

Zones and Correlations

The most geographically widespread reefs occur within the Crown Point and lower Valcour formations; more specifically, in the faunal divisions recognized by Raymond (1906, p. 565–566) as Division 2, that of *Maclurites magnus* Le Seuer, and in Zone 3a of Division 3, the zone of *Glaphurus pustulatus* Walcott.

Maclurites magnus is observed in at least fair abundance in all facies of the middle Chazyan Crown Point, while *Glaphurus pustulatus* seems quite rigidly confined to very pure calcilutites accompanying the lower Valcour reefs and rarely has been reported elsewhere(Raymond 1906, p. 543). *Rostricellula plena* Hall is said to occur in the *Glaphurus*-bearing reefs, (Raymond, 1906, p. 566), but the author has discovered none with *Glaphurus pustulatus* or below and restricts his usage of "*Rostricellula plena* zone" to beds containing this form in abundance and lying above the last occurrence of *Glaphurus pustulatus*. These are essentially the zones 3b and 3c of Raymond.

Difficulties have arisen in the past over the placement of the Crown Point-Valcour contact, particularly in the basinal facies sections. In referring to Isle La Motte, only six miles from the type section, Perkins (1904, p. 123) said, "In some places we found great difficulty in separating the Upper Chazy from the Middle and in some instances we failed to find a dividing line." This was before the excellent faunal studies of Raymond, but the uncertainty still exists in sections without *Glaphurus*-bearing reefs except at Chazy, where the contact by definition is a distinct lithologic change.

It is not the purpose at this writing to introduce stratigraphic names eventually needed to clarify the relationship regionally, but to describe the facies

changes which give rise to the problem. From the type section of the Chazy group (Section 1) the discussion will move to one of similar facies at Jordan Point, Isle La Motte (Section 2); thence to the intervening points where reefs occur.

NORMAL FACIES SECTIONS

Chazy, New York

The type section of the Chazy lies in a series of gently tilted fault blocks. The major details of thickness, lithology and distinctive faunal content are printed as Section 1 under "Stratigraphic Sections" and shown graphically in Figure 2. Pertinent to this discussion are the relatively large thickness of the formations, totaling some 617 feet with the base covered; and the absence of known reef deposits in the Day Point and the *Rostricellula plena* zone of the Valcour. Neither the Day Point nor Valcour calcarenites here display the highly-inclined cross-lamination seen in other localities. The preponderance of this lithology combined with the known relatively restricted, regional extent of the two formations does, however, suggest shallower water conditions than those pertaining during the intervening regionally Crownpoint overlapping deposition.

The Crown Point limestones are a remarkably homogeneous 250 foot sequence of dark-blue gray, moderate- to heavy-bedded argillicalcisiltites. Distinctive features are the irregular buff-silty laminations which, when closely spaced, cause the rock to weather to nodular surfaces. Two exceptional lithologies in this section are the fairly coarse, cross-laminated calcarenites, appearing about 50 feet above the base, and the mildly reefy *Stromatocerium*-bearing horizon at the 123 foot level. The former is about 24 feet, the latter 8 feet. In Figure 2 covered intervals are shown as argillicalcisiltite. They may well be of some other less resistant lithology, but are probably not reefs nor calcarenites which outcrop widely in many other localities and generally equal or exceed the argillicalcisiltites in topographic expression.

The contact of the Crown Point and Valcour limestones is a sudden lithologic change. The lower Valcour is of massive, silty, brown-weathering dolomites and light gray, dense calcilutites, the latter so much like the type Lowville that Emmons (1841) so misidentified them. Above this suite of beds, which total 16 feet, there lies a distinctive 2-foot dolomitic calcisiltite crowded with shells of *Lophospira rectistriata* Raymond, encrusted and usually enclosed by thick, well-formed lamellar structures of *Girvanella sp.* Completing the exposure of Valcour below the *Rostricellula plena* zone are about 5 feet of less fossiliferous calcisiltite and coarse calcilutite. These are followed by a covered interval of 23 feet, which by its non-resistant nature suggests the impure limestones of the overlying zone and is for this reason alone placed there in Figure 2.

These strata are lowest Valcour by definition. Their lithology offers little on which to base an interpretation of water depth during deposition. Lithologies and the algae-encrusted shells argue for limited current and wave action such as might exist in either relatively deep waters or protected areas of shallower seas, perhaps a lagoon. The relatively large proportion of dolomite might indicate concentrations of magnesium in depositing waters.

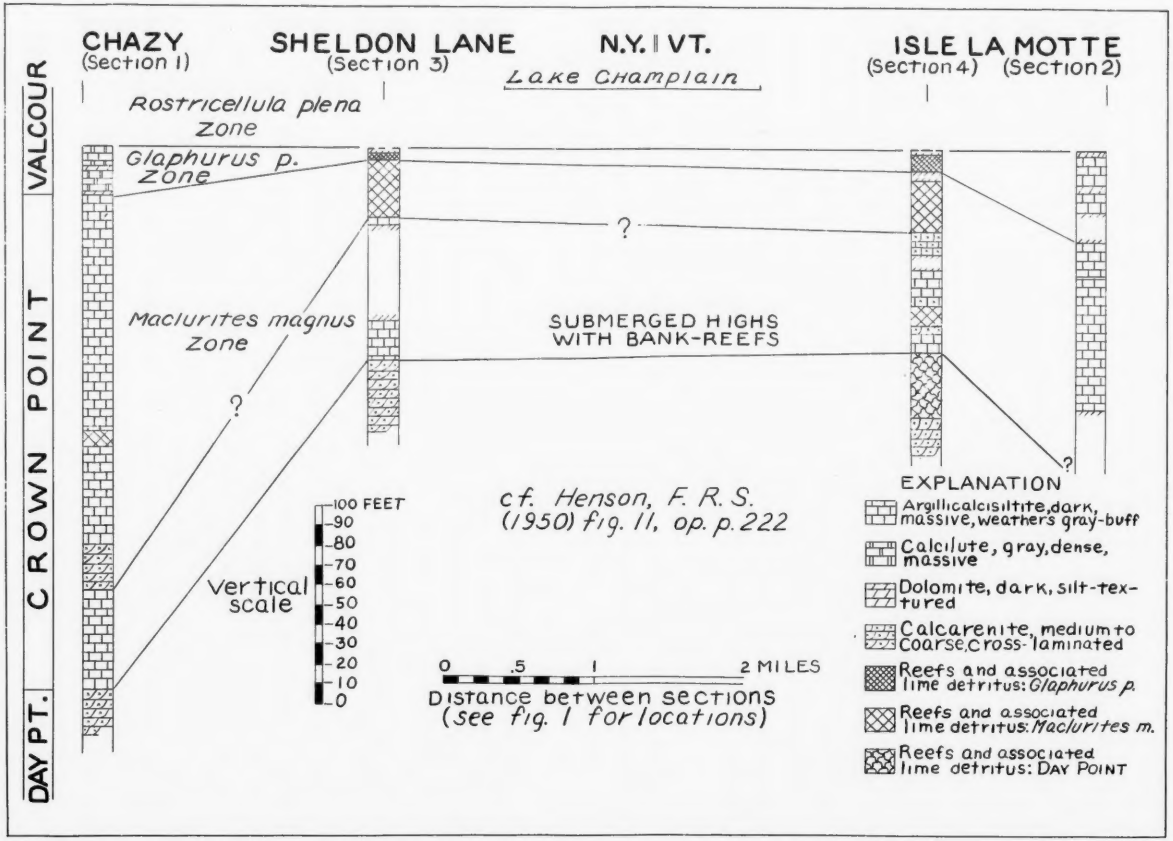

FIG. 2. Relation of Chazyan sections in northern Champlain Valley

Jordan Point, Isle La Motte

The Jordan Point section, on the eastern shore of Isle La Motte, is at the eastern extremity of the trend under consideration. There compressional effects of the Taconic orogeny add some structural complexity, and the compilation of the section shown in Figure 2 is open to question. The uncertainties of correlation on lithologic grounds could, however, introduce an error only in thickness of the lowest Valcour, not in the general nature of the deposits.

Since both the base of the Crownpointian *Maclurites magnus* zone and all but the lower 3 feet of the *Rostricellula plena* zone are covered, little can be said of the stratigraphic frame in which the *Maclurites* beds and lowest Valcour are set. The exposed *Rostricellula* beds are mildly reefy in structure and highly fossiliferous, particularly in numbers of bryozoans.

The Crown Point strata at Jordan Point are similar in all respects to the normal argillicalcisiltites at Chazy. There are no calcarenites nor reefy lithologies in the 84-foot exposure. *Maclurites magnus* is common in all but about the upper 10 feet.

The succeeding 47 feet of beds directly underlying the basal *Rostricellula*-bearing, reefy horizon are devoid of known *Maclurites magnus*. They are preponderantly of argillicalcisiltite, more impure than the underlying Crown Point and containing considerable quantities of silty, buff dolomite in brown-weathering, irregular seams. Dense dolomites are found near the base and in the upper 1 foot 9 inches.

This sequence is correlated with the lower 24 feet of Valcour at Chazy by reason of similar stratigraphic position between the zones of *Maclurites magnus* and *Rostricellula plena*. If this correlation is correct, there seems to have been no striking local change in conditions of deposition from those pertaining during the preceding Crownpointian.

REEF FACIES SECTIONS

Sheldon Lane, New York

Lying two miles from the type section at Chazy are exposures whose contrasting character and thickness cannot but impress the observer with the rapid lateral variation of the Crownpointian and lower Valcourian deposits.

Here the underlying Day Point is of calcarenite which displays highly inclined cross-lamination of the torrential type. The *Rostricellula* zone is covered.

The lower 71 feet of the Crown Point, where exposed, is normal argillicalcisiltite as at Chazy and Jordan Point with the exception that basal beds are quite calcarenitic and contain heads of *Stromatocerium* sp. In the upper 30 feet are *Stromatocerium* reefs with associated *Maclurites*-bearing calcarenites. The total formational thickness of 101 feet is but 40% of that at Chazy, the rate of convergence being about 75 feet a mile.

The Crown Point reefs outcrop widely south of Sheldon Lane as small, light gray-weathering, hummocky klintar forming rounded knolls or ridges no more than 4 feet high and extending about 150 yards along the northward strike. The

formation lies on the crest and eastern flank of a gently north-plunging, low anticline. This structure is bounded by an unexposed fault paralleling its axis and probably lying about 400 yards to the east. The adjoining downthrown block to the east is Trenton, little exposed in lower ground toward the lake.

The single reefs are not more than 4 feet in thickness. They are composed of the grayish-white, finely crystalline calcite structures of *Stromatocerium* spp., whose finely lamellar expansions may be traced for several feet on weathered surfaces. Intimately associated are bryozoan-filled patches also mainly of light gray finely crystalline calcite. Enclosing and filling the whole is medium to dark gray calcilutite or fine calcisiltite containing abundant *Zittelella varians* (Billings), *Billingsaria parva* (Billings), and fragments of *Bumastus globosus* Billings, *Isotelus harrisi* Raymond and other trilobites. Brachiopods are not abundant, nor are they well preserved. *Leptaena incrassata* Hall is fairly common. Cephalopods are abundant in limited pockets of the reef and are invariably filled with coarsely crystalline calcite. Brownish, silty to sugary dolomite irregularly replaces small portions of the reef rock, often following the boundaries of *Stromatocerium* layers.

Underlying, flanking, and filling channels between the reef hummocks are medium to light gray, brownish silty, coarse calcarenites commonly made up primarily of cystid stem fragments and containing small, well-rounded dolomitized pebbles. The calcarenite is draped over the reef masses at low initial dips and shows gently inclined cross-lamination, especially in the more regular beds underlying the reefs. It is very fossiliferous, but smaller forms are found as fragmental debris. *Maclurites magnus* is common to abundant in this lithology to the top of the formation.

Across Sheldon Lane to the north is a small quarry which exposes a 6 to 8 foot section of rock at the top of the *Maclurites*-bearing reef horizon. Here it is generally massive, normally bedded, medium to fine calcarenite containing numerous *Öpikina? champlainensis* (Raymond).

The lithology of the *Maclurites*-bearing reef complex is so variable that measured sections taken 20 feet apart might show considerable discrepancy of detail, and 20 yards from an exposure of well-developed reefs there might be none, although it is probable that their presence nearby would be indicated by a more or less calcarenitic lithology, as in the quarry mentioned. The reef rocks and the state of enclosed fossils attest to strongly agitated waters, probably in a zone of breakers. Only the more obvious portions of the fauna have, as yet, been studied.

North of Sheldon Lane and overlying the reefs just described are others varying only slightly from them in lithology but strongly in faunal content. In these the calcilutites are light gray, very dense, and pure, especially toward the top of the 3-foot exposure. *Maclurites* is absent. *Glaphurus pustulatus* cranidia are common, but only in the purest of the calcilutite. *Bumastus globosus* (Billings) is abundant and *Tetralichas minganensis* (Billings) and *Isolelus harrisi* Raymond common. This is the Station M_{133} of Raymond (1906, p. 545). Species of the rich cephalopod fauna have also been described from this horizon and locality by Flower (1943). The cephalopods are invariably filled with rather coarse

calcite which may in turn be cracked and recemented by similar material (Flower, 1950).

These are typical reefs of Raymond's *Glaphurus pustulatus* zone, as seen at Smuggler's Bay, Valcour Island, and south of Rockwell Bay, South Hero, Vermont (Plate 1). In both these localities such reefs are immediately or closely overlain by beds of the *Rostricellula* zone. They are correlated on similar stratigraphic position with the lower 24 feet of the Valcour at Chazy, and these latter, and correlatives at Jordan Point, Isle La Motte, may be referred to as *Glaphurus pustulatus* zone, although the species has not been found in the non-reefy facies.

Central Isle La Motte

The finest display of the Crownpointian and excellent exposures of the lowest Valcourian reefs are to be seen on south-central Isle La Motte. They form ledges and small klintar on the slopes and crest of a hill, and good outcrops are found for about three-quarters of a mile northward toward The Marsh which bisects the island.

Below the reefs and their underlying normal argillicalcisiltites are well developed bioherms in the upper 25 feet of the Day Point formation. The *Rostricellula* beds are covered or lost by erosion in this area.

The lower contact of the Crown Point is poorly exposed and perhaps quite irregular as it lies on the Day Point reefs. The lower 40 feet, with the exception of a calcarenitic zone near the base, is typical dark blue-gray argillicalcisiltite in moderate to heavy beds, some of which have been quarried. Above a narrow covered interval the rock changes to medium-grained massive calcarenite in which *Maclurites magnus* is extremely abundant. This grades into some 30 feet of reefs containing the same form, abundantly near the bottom and rarely toward the top (Pl. 2).

The Crown Point reefs are very similar in faunal content and lithology to those at Sheldon Lane but are more massive, some as much as 10 feet without intervening calcarenite. Features of the reef-rock and associated detritals are shown in plates 2, 3, 4, and 5.

Glaphurus-bearing reefs comprise the uppermost exposures and the trilobite is again confined to the purest pockets of calcilutite, particularly those in the upper foot of the section. The lower 10 feet of this *Maclurites*-free sequence is not truly biohermal in these exposures, but is of coarse, impure calcarenite in which bryozoans are abundant.

Conditions of sedimentation must have been nearly identical at Sheldon Lane and central Isle La Motte during Crownpointian and earliest Valcourian times.

COMPARISON AND CONTRAST OF SECTIONS

Thickness and Lithology

The four described sections are graphically compared in Figure 2. The chart emphasizes thickness and lithology and their relation to reef occurrences. The following relationships are drawn from the data presented:

1. Where well-developed reefs are present higher in the section, the upper Day Point is also reefy or consists of steeply cross-laminated calcarenites.

2. In all sections, reef or normal, at least the lower 40 feet of the Crown Point is predominantly of argillicalcisiltite.

3. Calcarenites occur in limited zones of the Crown Point in sections without reefs.

4. The Crown Point thickness is greater (as much as 250%) in the normal than in the reef facies. The thinnest section contains the thickest reef deposits.

5. Normal facies sections of the *Glaphurus pustulatus* zone contain bedded dolomites and magnesian limestones in quantities not seen at other horizons.

6. Normal sections of the *Glaphurus* zone appear to be notably thicker than reef facies. Obscured upper reef contacts preclude a definite statement.

Faunules

A listing of species present in the sections described would represent little advance over the careful work of Raymond (1906), who also made numerous observations on their relative distribution and abundance. Comparison of these with data obtained during the present study emphasizes the following pertinent relations in the local Crown Point. These may not obtain in other localities.

1. In the type section's normal facies at Chazy, *Maclurites magnus* LeSeuer is present and often abundant throughout the entire 250 feet of Crown Point. Raymond's statement to the contrary (p. 549) is in error probably due to inability to observe the uppermost 42 feet, part of which is now exposed in a small quarry. This gastropod persists in at least moderate, and often great abundance in the calcarenites of 29 feet of strongly reefy Crown Point at Sheldon Lane. It is absent in the overlying *Glaphurus*-bearing reefs. At Isle La Motte (section 4) it does decrease in abundance toward the top of the reefs below the *Glaphurus* zone, however it seems to be practically devoid of critical facies control and is therefore thought to be a dependable guide to correlation in this area.

2. Although present in associated, coarser detritals, *Maclurites* and other gastropods are not commonly found in the Crown Point reef masses proper, nor are brachiopods and *Girvanella* sp.

3. Cephalopods, bryozoans, corals, sponges and *Stromatocerium* show a distinct concentration in the reef facies, and are most abundant in the reefs proper or in cavities therein, which are filled with fine calcisiltite or calcilutite.

4. Trilobites seem to occur in almost equal abundance in reef and normal facies. They are physically, if not ecologically concentrated in the former.

Associations similar to those of the biohermal Crown Point are found in the *Glaphurus*-bearing reefs. Raymond (p. 550) lists and comments pertinently on their fauna. The normal facies of the lowest Valcour is poor in fossils. Too little study has been made of it, but the absence of *Glaphurus pustulatus*, so common in equivalent reefs, points to this as one of the few strictly "facies fossils" in the sections studied.

PALEOGEOGRAPHY AND HISTORY

The seas of earliest Crownpointian time must have been deep enough to generally mask the irregularities of bottom elevation indicated by the relatively slight contrasts in latest Daypointian facies, along the line of sections. However by middle Crownpointian time, irregularities of similar form and greater relief

appeared. These were sufficient to cause a distinct change in the type of sediments at Sheldon Lane and central Isle La Motte. It seems probable that these areas were tectonically uplifted, and over the submerged highs grew the predominantly hydrocoralline reefs.

Strong wave and current action over the reef areas maintained finer sediments in suspension and by this winnowing process carried them into the deeper, stiller waters. There they contributed to the greater thicknesses of the normal facies in the basins, which continued to sink to the east and west.

The reefs, though small, are best termed bank-reefs as defined by Henson (1950, p. 227). The general conformation of deposits and relationships of facies in the Chazy are suggestive of portions of those he illustrated from the Tertiary and Upper Cretaceous of the Middle East (fig. 11, op. p. 222).

Over the bank-reef areas, no change in conditions of sedimentation marks the beginning of Valcourian time. In the neighboring basins, the increased dolomite content might indicate more restricted circulation in areas more or less bounded by the reefs. This postulated effectiveness of the reef areas as barriers in early Valcourian time is not in accordance with their behavior during the Crownpointian and would necessitate either renewed uplift of the formerly more deeply submerged highs or a general regression of sea. The latter is suggested by the offlapping of the Valcour in the southern Champlain valley. To carry this conjecture further would be impertinent. It is one of several lines of thinking which may be more certainly developed or discarded when more is known of the regional pattern of the reefs and synchronous sediments.

STRATIGRAPHIC SECTIONS

The four measured sections are arranged in order of discussion. No. 3 and No. 4 are found in undisturbed structural continuity. The figures in column I are thicknesses of individual units. Figures in column II represent cumulative thicknesses of formations. Only portions of the sections pertinent to this paper are detailed.

1. Chazy section: Compiled from ridges in fields 1 mile S45W of center Chazy, N. Y. General dip 11°, S54E.

	Thickness (feet and inches) I	II
"Lowville" calcilutile:	—	—
Valcour limestone:		
2. Zone of *Rostricellula plena* (Hall)		
Calcarenites, medium to light gray, more or less argillaceous and buff silty in 1 to 3 ft. beds; *Rostricellula plena* Hall, *Mimella vulgaris* Raymond, and ramose bryozoans abundant; about	90-0	137-2
Covered interval	23-0	47-2
1. Zone of *Glaphurus pustulatus* (Walcott)		
Calcilutite, light gray, coarse, massive; grades into the underlying	3-9	24-2
Calcisiltite, dark gray	1-0	20-5

	Thickness (feet and inches) I	II
Calcisiltite, medium gray, fairly pure; weathers in mottled gray tones	0-6	19-5
Calcisiltite, slightly greenish gray, dense, massive; rough gray- and brown-mottled on exposure with abundant sections of *Lophospira rectistriata* Raymond enclosed in *Girvanella* sp.	2-0	18-11
Calcilutite, medium dark gray, pure, massive; fine white crystalline calcite fillings	2-10	16-11
Dolomite, iron gray, silt textured, massive; khaki-brown weathering	2-9	14-1
Calcilutite, medium dark gray, pure, massive; fine calcite fillings, (typical Lowville lithology)	4-8	11-4
Calcilutite, dark, dirty gray, dolomitic; weathers light brown in 1 to 2 ft. beds	5-8	6-8
Dolomite, light yellowish gray, silt textured, weathers light brown.	1-0	1-0
Crown Point limestone:		
Calcisiltite, yellowish gray, slightly dolomititic; 7 in. beds	1-2	250-2
Calcisiltite, light gray, dense containing greenish dolomitic silt impurity; *Maclurites magnus* (many juveniles) very abundant with large orthocerocones	3-9	249-0
Calcisiltite, dark, dusty gray, dense and brittle, barren; weathers in brown and gray laminae .5 to 1 in. apart	6-7	245-3
Covered interval	11-0	238-8
Argillicalcisiltite, dark gray, buff silty; in 1 to 2 in. laminae weathering to nodular light gray rubble	11-3	227-8
Calcisiltite, very dark blue-gray, dense and massive in heavy ledges; *Maclurites* very abundant in lower 8 ft; upper 4′ more argillaceous	10-11	216-5
Argillicalcisiltite, dark blue-gray with buff silty laminae; weathers in slabby and nodular shaley rubble. 5-5 covered 2-6 from base	17-11	205-6
Argillicalcisiltite, dark blue-gray, fairly pure, heavy ledged; weathers smooth light gray; *Maclurites* common	4-4	188-4
Covered with exception of 2-1 argillicalcisiltite, dark blue-gray, 25-6 from base	52-1	184-0
Argillicalcisiltite, dark blue-gray, impure, calcarenitic; in mildly reefy, shaley-weathering beds; large colonies *Stromatocerium* sp., *Maclurites*. Upper 8 in. not reefy	8-7	131-11
Covered interval	28-0	123-4
Argillicalcisiltite, dark blue gray, 2 to 3 ft. beds; *Maclurites* abundant, silicified on surfaces	11-6	95-4
Covered interval	7-0	83-10
Argillicalcisiltite, dark blue-gray, buff silty and calcarenitic; nodular shaley-weathering with abundant *Maclurites*	1-6	76-10
Calcarenite, medium gray, medium-grained, pure; cross-laminated in 3 to 5 ft. beds	15-4	75-4
Calcarenite, medium gray, medium coarse-grained; strongly cross-laminated in 1½ to 3 ft. beds; large proportion is cystid fragments	9-2	60-0
Argillicalcisiltite, dark gray, with buff silty laminae on weathered surfaces; massive but weathering in 1 to 2 in. irregular layers; upper 1 ft. crowded with *Girvanella* sp.	5-7	50-10

	Thickness (feet and inches) I	II
Covered interval	10-0	45-3
Argillicalcisiltite, dark blue-gray, finely calcarenitic with buff silty laminae on gray weathered surfaces; 1 to 2 ft. beds; *Maclurites* common to abundant	35-3	35-3
Day Point limestone:		
Calcarenites, medium to light rusty gray, medium- to coarse-grained; often largely of cystid stems; more dolomitic near base of exposure which is not complete; fossiliferous; *Plectorthis exfoliata* Raymond abundant except near base, *Raphistoma stamineum* Hall and *Lophospira rectistriata* Raymond common toward top	230-0	230-0
Covered interval	—	—

2. Jordan Point section: Compiled from ledges on Jordan Point, inland, and south to Lake Survey marker on shore 1.1 miles S47E of Isle La Motte village, Vt. Note: Contact of Valcour and Crown Point uncertain. Error in correlation based on lithology might add maximum of 27 ft. to base of Valcour as shown.

Valcour limestone:		
2. Zone of *Rostricellula plena* (Hall)		
Covered by The Marsh about	70-0	119-11
Reefy argillicalcisiltite containing silty brown dolomite patches and pockets of calcarenite and calcilutite, highly fossiliferous; *Anolotichia* sp. aff. *A. explanata* Coryell and smaller, ramose bryozoans abundant; *Rostricellula plena* (Hall), *Mimella vulgaris* (Raymond) common; *Bumastus globosus* (Billings) and *Meniscoceras* sp. abundant in pockets	3-0	49-11
1. Zone of *Glaphurus pustulatus* (Walcott)		
Dolomite, dark gray, silty, massive; weathers brown, closely jointed	1-9	46-11
Argillicalcisiltite, dark gray, dolomitic, massive; weathers to gray-brown pitted surface. 6-8 covered 2-3 from top	14-11	45-2
Dolomite, dark gray, dense, silty; weathers brown, fractures conchoidally	3-7	30-3
Argillicalcisiltite, dark gray, moderate beds; weathers gray with brown silty laminae; lower 5-0 massive	12-6	26-8
Covered interval	14-2	14-2
Crown Point limestone:		
Argillicalcisiltite, gray, moderately bedded; weathers mottled gray-brown	17-5	84-4
Calcilutite, black, and dolomite, brown-weathering; finely laminated	0-4	66-11
Argillicalcisiltite, dark gray, fairly pure, moderate beds; few argillaceous seams and stylolites	2-10	66-7
Similar, purer; fractures conchoidally	2-9	63-9
Similar, more argillaceous	3-0	61-0
Argillicalcisiltite, brownish gray, massive; weathers in gray and buff bands; contains *Maclurites magnus*	14-0	58-0
Similar in 1 to 6 ft. beds; *Maclurites* common; to base exposure	44-0	44-0
Covered interval	—	—

3. Sheldon Lane section: Exposures north and south of Sheldon Lane, 2 miles S40E of center Chazy, N. Y.

	Thickness (feet and inches) I	II
Valcour limestone:		
Covered interval	—	—
2. Zone of *Glaphurus pustulatus* (Walcott) Reef; mainly of medium to very light gray, dense calcilutite; *Glaphurus pustulatus* (Walcott) common in pure light gray portions; contains: *Billingsaria parva* (Billings), *Stromatocerium sp.*, *Leptaena incrassata* Hall, *Tetralichas minganensis* (Billings), *Bumastus globosus* (Billings), *Isotelus harrisi* Raymond and numerous cephalopods	3-0	3-0
Crown Point limestone:		
Reef: knobs of more or less pure bluish-calcilutite surrounded by light gray, coarse- to medium-grained impure calcarenite, the latter weakly cross-laminated; *Stromatocerium* sp., *Zittelella varians* (Billings), small ramose bryozoa, and fragmental trilobites common in calcilutite; cystid stems abundant in calcarenite; with *Maclurites magnus* and *Öpikina? champlainensis* (Raymond) in associated beds	5-0	100-11
Similar, but with moderately regular bed of dark, fine-grained calcarenite; *Maclurites* common	16-0	95-6
Calcarenite, medium gray, fine-grained	1-0	79-6
Calcarenite, mildly reefy with light gray fine-grained knobs; contains *Stromatocerium* sp., and *Maclurites*	7-2	78-6
Argillicalcisiltite, dark blue-gray; heavy-ledged but weathering in irregular 1 to 2 in. laminae; *Maclurites* abundant	3-11	71-4
Covered interval	48-5	67-5
Argillicalcisiltite, dark blue-gray, impure; weathers to shaley, slabby rubble; *Maclurites* common	5-8	19-0
Argillicalcisiltite, dark blue-gray; in 1 to 2 ft. beds; *Stromatocerium* sp. common	11-4	13-4
Argillicalcisiltite, medium gray, calcarenitic; in 1 to 2 ft. beds; massive toward top; *Stromatocerium* sp. and *Maclurites* abundant in lower part which weathers to nodular rubble	2-0	2-0
Day Point limestone:		
Calcarenites, mostly light gray, coarse-grained, impure; strongly cross-laminated in 1 to 4-ft. beds	43-0	43-0
Covered interval	—	—

4. Central Isle La Motte section: Exposures in abandoned quarry and on hill 1.7 miles due S. Isle La Mottle village, Vt. General dip 4°, N30W.

Valcour limestone:		
Covered interval	—	—
2. Zone of *Glaphurus pustulatus* (Walcott) Reef: mainly of very light gray, pure, dense calcilutite; *Glaphurus pustulatus* (Walcott) cranidia abundant in purest pockets	1-0	13-2
Calcarenite, brownish-gray, coarse, impure, massive; small ramose bryozoans abundant. Grades vertically and laterally into reef knobs	6-9	12-2
Covered interval	5-5	5-5

	Thickness (feet and inches) I	II
Crown Point limestone:		
Reef: bluish-gray calcisiltite, dark calcilutite, and surrounding calcarenites; the latter often completely replaced by brown-weathering, silty dolomite; *Maclurites* rare; *Zittelella varians* (Billings), and *Stromatocerium eatoni* Seely abundant; numerous cephalopods	4-6	85-11
Argillicalcisiltite, dark gray, mildly reefy structure; *Girvanella* sp. common	5-3	81-5
Reef: preponderantly fine calcisiltite to calcilutite crowded with *Stromatocerium* spp. and *Zittelella v.*; light gray, coarse calcarenites surround and fill channels in reef mass and are replaced by silty, brown-weathering dolomite which also pervades other lithologies; *Billingsaria parva* (Billings), *Maclurites m.* and several species of cephalopods common; very few bryozoa, *Dianulites* sp. aff. *D. petropolitana* Dybowski	13-3	76-2
Similar	3-0	65-11
Calcarenite, light gray, medium-to coarse-grained; considerable white crystalline calcite, and with dark, elliptical dolomitized pellets to .5 in. in lower 2-6; regular or gently inclined laminae, 1 to 3 in. in 2 to 7 ft. beds; *Stromatocerium* sp., *Zittelella v.* common, *Maclurites m.* extremely abundant in upper 7 ft	13-10	62-11
Covered interval	8-8	49-1
Argillicalcisiltite, dark blue-gray, moderately heavy-ledged quarry rock; contains *Stromatocerium* sp., *Maclurites m.*, and *Multicustella platys* (Billings)	12-8	40-5
Calcarenite, medium gray, medium-grained, oolitic	1-0	27-9
Calcarenite, medium light, brownish-gray, medium-grained; crowded with cystid stems; mildly cross-laminated in .5 to 2 in. layers, 1 to 3 ft. beds; *Stromatocerium* sp. common, *Maclurites m.* in upper 1 ft	6-10	26-9
Reef: mainly of light gray, medium to coarse calcarenite crowded with small ramose bryozoans and cystid fragments; irregularly dolomitized in hummocky masses. May be continuation of Day Point reefs	6-7	19-11
Calcarenite, medium, brownish-gray, medium-grained, dolomitic; upper contact irregular	3-4	13-4
Covered interval, except for poorly exposed *Maclurites*-bearing argillicalcisiltite	10-0	10-0
Day Point limestone:		
Reefs: dolomitic calcisiltite and silty brown-weathering dolomite knobs surrounded and filled by cystid-stem calcarenites; crowded with small ramose bryozoans; about	25-0	193-0
Calcarenite overlying thin basal quartz sands	168-0	168-0

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PLATE 1. Lowest Valcour reef, Rockwell Bay, South Hero, Vermont. Reef is partially awash in foreground. Regularly bedded *Rostricellula* calcarenites form overlying ledges in background.

PLATE 2. Base of Crown Point reefs, central Isle La Motte, Vermont. Hammer lies on reef. Loose blocks at base of ledge are underlying calcarenites crowded with *Maclurites*.

PLATE 3. Dolomitization in Crown Point reef, Isle La Motte. Hammer lies parallel to 2 to 3 foot band of darker, brown-weathering dolomite lying in gray reef limestone.

PLATE 4. Arcuate contact of Crown Point reef knob and calcarenite, Isle La Motte. Compass lies on reef proper. Deeply weathered trough marks sharp contact.

PLATE 5. Weathered reef exposure, top of Crown Point, Isle La Motte. Knife lies on blob of calcilutite in the midst of highly fossiliferous pockets. Cephalopods are particularly abundant with *Stromatocerium*, bryozoans, and *Billingsaria parva*.

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